# Augmented Reality Experiences for the Operator 4.0*

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## ABSTRACT

Virtual manufacturing has resurfaced and become the time of the hour - when entire production industries had to halt due to an unprecedented pandemic. This situation raises questions such as - Is a complete "virtual manufacturing" process even possible? How can an Operator stay well- and super-informed in such environments and make timely decisions? How can he collaborate effectively in virtual reality? Mixed Reality offers the opportunity to provide real-time information in an inobtrusive way, promising travel and cost-savings. An Operator wearing a set of smart glasses or holding a tablet receives individualized and real-time information about production order and status. His augmented experience motivates him to absorb information, and reduces his need to be physically present. Real-time sensor data make his information accurate. Digital twins enrich his visual experience, rendering him/her with a deeper understanding of the production processes. Maintenance instructions on augmented reality (AR) make his life easy, while performing expensive repair procedures. Collaborative tools in virtual reality enrich his possibilities to teleport and work with other co-creators. With practical demonstrations and use cases, we present proof-of-concepts of systems conceived for the Operator 4.0, with demonstrations and evaluations.

## KEYWORDS

Mixed Reality, Operator 4.0, Collaborative Tools, Internet of Things, Maintenance, Real-time Monitoring

## 1 Introduction

Industry 4.0 (also referred to as Cyber Physical Systems) allows new types of interactions between Operators and machines. In the wake of the pandemic, virtual manufacturing, which was merely a concept in earlier times, has now become the need of the hour. Virtual manufacturing is a simulation-based method that supports engineers to define, simulate, and visualize the manufacturing process in a computer environment. By using virtual manufacturing, the manufacturing process can be defined and verified early in the design process [1]. Combining the capabilities of virtual manufacturing with remote manufacturing leads to further possibilities, where distributed virtual enterprises with different capabilities emerge. These different capabilities encompass, but is not restricted to, several stakeholders – namely - design companies, suppliers, executing companies and customer-interfacing companies (which might be outsourced), and finally the manufacturing company, communicating with each other, and functioning virtually in a well-orchestrated manner. The challenge arises in information availability and consistency, where changes in one system, CRM systems in particular, are transmitted in real-time according to decision-making needs of different users, to production systems which operate with machines at the sensor-level. These interactions are demanding a new intelligent workforce that have the capacity to process and obtain information in a timely manner, that have a significant effect on the nature of work. The integration of workers into an Industry 4.0 system consisting of different skills, educational levels and cultural backgrounds is a significant challenge. The new concept of Operator 4.0 was created for the integrated analysis of these challenges [2].

In this work, we develop the requirements thereof, and present the prototypes of a system that centers on augmenting the Operator's maintenance processes using current AR technologies & suitable Operator devices. Specifically, we address the following research questions: What are the requirements and design considerations for an AR application that can be used to achieve maintenance services? Do instructional AR applications provide additional benefit to the Operator in terms of operability and usability? How does visualization of data using AR help in achieving maintenance goals - such as reducing maintenance errors, service costs, and saving downtime during maintenance?

This paper is structured as follows: Chapter 2 presents the main terminologies and State of the Art in Operator 4.0 & related terminologies, and a summary of existing AR applications for maintenance. Chapter 3 posits the research questions, followed by presentation of requirements of an AR-based maintenance platform, design guidelines and presentation of two developed prototypes. Chapter 4 presents the results of a pilot usability & evaluation study. Chapter 5 concludes and discusses the limitations.

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## 2 State of the Art

In the following chapter, we present the Operator 4.0 taxonomy and the various tenets of this vision from a technological and conceptual point of view. Following this, we present the benefits and limitations of AR as a technological choice for maintenance processes.

### 2.1 Operator 4.0

The Operator 4.0 terminology focusses on human centricity, laying the Operator at the center of the design process – of a smart factory, that is suited for workers of all capabilities. The systems designed for the Operator aim to empower and engage the workers, while enabling knowledge sharing, and ensuring data transparency across multiple systems in the supply chain. A more advanced goal is participative work place design, where Operators along with other stakeholders, dynamically co-create their workspaces and digital technologies for manufacturing processes.

The move towards virtual enterprises, has redefined the nature and definition of work. System designs that consider different capabilities of the Operator, his/her attention & cognition levels, real-time informational needs, and that utilizes spatial & analytical capabilities of the human mind in an optimal way, are emerging concepts in the Operator 4.0 taxonomy [2]. Particularly of interest is the technology spectrum of Operator 4.0: Analytical Operator, augmented Operator, collaborative Operator, healthy Operator, smarter Operator, virtual Operator, amongst others. Each objective can be achieved by using its specific technological counterpart (Artificial Intelligence (AI), Internet of Things (IOT) Protocols, AR, Collaborative & Virtual Reality, Wearables, amongst others), which demand industry-specific design and development strategies.

Industry and academics define digital twin in different ways, it is generally accepted that a digital twin is an integrated multi physics, multiscale probabilistic ultra-realistic simulation of systems and products which can mirror the life of its corresponding twin using available physical models, historical data and real time data [3]. We build on the definition of digital twin [4]- as a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them. In addition to the mapping, a digital twin allows for a visual understanding of real-time production information, enabling interaction with production components (from monitoring to production control).

Digital twins combined with cloud systems promise a plethora of advantages – from providing the right information and access rights to stakeholders within an enterprise, to facilitating the dream of a distributed virtual enterprise that function across different systems and firms in the supply chain. Combined with personalization, cloud-based Customer Relationship Management (CRM) technologies (such as SmartWe) have the potential for enabling the Operator 4.0 experience. We focus on studying how distributed teams can be supported during their day-to-day-work in small and medium-sized companies, and examine how information can be conveniently presented as a digital twin across multiple systems and devices.

### 2.2 Augmented Reality for Maintenance

The use of AR for maintenance purposes has increased in the recent years, particularly with the advent of AR glasses suited to rough industrial usage. Table 1 contains an overview of AR-based maintenance systems. Following is a list of common examples where AR has been applied for industrial purposes.

1. Plant Design: Visualization of the layout in the factory [7].
2. Product Design: Visualization of 3D models in presentation and prototype making [7].
3. Production Assistance: AR application is expected to provide virtual assistance by visualizing sensitive information, product assembly and equipment on the shop floor [7] [8] [9].
4. Training: Simulation of training and production process optimization [10].

**Table 1: Overview of existing AR Maintenance Systems**

| Authors | Purpose of research | AR Innovation element |
|---|---|---|
| Rose et al. 1990 | Annotate real-world objects | The application was able to name and label the parts of the engine using augmentation |
| Columbia University researchers | Self-guided AR system | AR prototypes for inspection, construction and renovation industry |
| Yim & Seong 2010 | To mitigate accidents in the nuclear power plants and for guidance. | Maintenance activity of Wilo 801 pump in the nuclear power plant was carried out |
| Gurewich et al. 2012 | Remote Collaboration | AR was used to provide collaboration between inexperienced technicians and experts located off-site |
| Benbelkacem et al. 2013 | Remote assistance in maintenance on a critical equipment | Photovoltaic water pumping system was repaired using a remote AR application. |
| Koch et al. 2014 | Reduce the repair time and cost | The application uses markers to guide the user to the maintenance area and provides instructions to perform repair activities |
| Wang et al. 2014 | Expert guided system for machine maintenance | Expert who is not available on-site was able to control and provide the instructions through the AR system |

Some of the potential benefits of AR in maintenance have been identified based on a literature review of existing application. We enlist the relevant ones for the Operator 4.0 terminology below.

*2.2.1 Benefits of AR-based Maintenance Systems.*

1. **Reduced head and eye movement**: This is a consequence of providing the augmented virtual content that is otherwise

presented in paper document manuals, online and offline references. This would improve the health, efficiency, and endurance of the Operator by decreasing his/her work-load [5].

2. **Reduced context Switching:** The time duration of an Operator's focus on the subject of repair can be maintained and even increased by superimposed virtual content, reducing the cognitive and mental cost in context switching, and thereby increasing the productivity of the Operator.
3. **Reduced repair sequence time**: AR applications are helpful in reducing the overall repair time through the labels, arrows, annotations, animations cueing information that aids the Operator and thus potentially reduces the required transition time for an Operator to transit over the spatially extended sub-tasks.
4. **Real-Time collaboration**: AR applications could also provide remote assistant features by sending the data for the maintainer, repaired components, repair parts, and the tools over the shared network, through an app or through AR glasses, thus enabling experts or service providers to remotely monitor the maintenance and provide virtual remote assistance.
5. **AR training application**: AR applications can be used for onboarding activities. This application can be flexible in their usage and support various operation techniques which provide information either entirely or real-world objects, or completely virtually, or in a blended manner. Example use cases include, imposing artificial objects on to the equipment where maintenance is taking place, or to simulate an abnormal situation which does not occur frequently.

#### *2.2.2 Limitations of AR in Industry Maintenance*

1. **Data Integration and Availability:** In AR applications for maintenance and repair aiding, detailed 3D modeling with all components of the equipment is necessary to augment the virtual content and that confines the application's scope to the availability of detailed 3D models. This requires modeling the components using expensive 3D scanners with CAD knowledge as well as manual design and post-processing.
2. **Design Complexity:** Ambitious tendency to apply new technology to a wide range of problems and settings is common in technology development. Such scenarios could be seen in the development and success of AR applications in the maintenance field. Instead, the focus must be on designing the complexity to relatively simple and targeted applications' high functionality to provide tangible solutions.
3. **Hand held devices (HHDs) restrictions**: Holding the smartphone device in front of them and pointing towards the desired equipment to be maintained to display AR-based maintenance information could be cumbersome and come in the way of machine operation [6]. Instead, a hands-free way of guidance to work with the machine during the maintenance would be helpful to the operator.

## 3 Research Question and Methodology

We posited the following research questions, based on our review of current literature and state of the art AR technologies.

RQ1: What are the requirements and design considerations for an AR application that can be used to achieve maintenance services?

RQ2: Do instructional AR applications provide additional benefit to the Operator in terms of operability and usability?

RQ3: How does visualization of data using AR help in achieving maintenance goals - such as reducing maintenance errors, service costs, and saving downtime during maintenance?

### 3.1 Literature Review

To address the first question (RQ1), we conducted a literature review to analyze the requirements of an AR technology for maintenance, keeping the role of German small & medium enterprise segment in mind. The following key requirements were identified:

4. **Data security:** Data security must be agreed upon by all parties concerned, and guaranteed upon any collection of factory-specific data. Certain laws or regulations must be followed to avoid conflicts between workers and their councils. This may remove the necessity of surveillance of employees during data recording or position tracking [11].
5. **Cost effectiveness:** The expense required or the investment costs of an AR application both during the development and integration in operative systems has to show the expected return [12].
6. **Applicable regulations:** Hygiene and safety in work are important regulations to be kept in mind while designing and integrating AR applications in a maintenance context [13], [14].
7. **Set-up requirements:** Set-up time: Within the industrial environment there should be minimal time required for AR applications set-up [7]. In setup time, duration required for repeated processes like cleaning and calibration need to be considered [15].
8. **System reliability:** The required maintenance of the application should be as minimal and reliable as possible [7].

Following additional requirements were identified in terms of ensuring operability of an AR Maintenance app.

1. **Accuracy of presentation:** To reduce the possibility of errors, the alignment of virtual objects and real-world must be accurate [15].
2. **Real-time capability:** To ensure more intuitive interaction in the application, tracking, and visualization of objects must be performed in real-time that reduces the chances of errors or motion sickness [7,15].
3. **Ergonomics:** AR applications are meant to be operated by the human in the human-machine interface, therefore the design and operation must be human-centric. Therefore, human factors such as the reduction in attention to avoid strain on eyes during operations for extended time are considered [15, 16, 17].

## 3.2 Design Guidelines

In an analogous manner, design guidelines for an AR maintenance app that focuses on the Operator were laid down as follows.

1. **Tracking & Registration:** Tracking and registration techniques are one of the most fundamental concepts in AR research today [18]. An AR system's main function is to keep track of the user's motion correctly and consistently to determine the user's position for the registration between the augmented 3D elements and the real world to provide the immersive AR experiences within the environment. Tracking with robustness and accuracy can lead to a good AR experience. Spatial attributes of the smartphone or the targets of augmentations are dynamically detected by the tracking process and thus tracking technique plays a major role in showing the augmentations at a certain location. Displaying the overlay of superimposed 3D objects onto the targets based on the tracking is accounted by registration [19]. Hence registration technique is related to the tracking process. Tracking methods are categorized as camera-based, sensor-based, Simultaneous Localization and Mapping (SLAM), or location-based.
2. **Visualization:** Head-mounted displays, head-worn projectors, and retinal displays are common types of head-attached displays that are to be worn by the user and there are also hand-held displays.
3. **Rendering:** The main goal of the rendering method is integrating graphical elements into the real-world that users are unable to distinguish between virtual objects and real ones [20]. Graphical objects must be integrated consistently into the real world. Consistent occlusion, inter-reflection behavior, and shadow-casting are primary guidelines that need to be followed [20]. OpenGL is one of the libraries used for rendering 2D and 3D graphics.
4. **Authoring:** Authoring is the process of creating animations and content for an AR application. Authoring mainly involves three components: designing and creating mesh 3D models, creating animated movements for 3D models, and aligning the 3D model's movements with the real-world objects. It also includes incorporating animated components and movements of 3D models, along with suitable text and symbols indicating instructions.
5. **Interaction techniques:** Interaction techniques are classified as Touch-Based (on-screen touch inputs), Mid-air Gestures-Based (finger gestures), and device-based (gestures specific to a tablet or a mobile device).

## 3.3 Concept & Prototype

To address the second research question (RQ2), we designed and developed two prototypes, to evaluate the benefits of an AR maintenance app to the Operator in terms of operability and usability. We present the two prototypes herewith. Figure 1 represents the software components used for the development of the prototypes.

**Prototype 1:** This AR system is for the maintenance of a common consumer appliance, namely a coffee machine (WMF 1100S). An office coffee appliance at CAS Software AG is chosen to develop a model-based target (Marker-less) AR system, with the aim to provide maintenance guide for non-technician or household users. The prototype on coffee machine is developed with the possible maintenance activities based on the available access to the Computer-aided Design (CAD) model of parts of the WMF coffee machine.

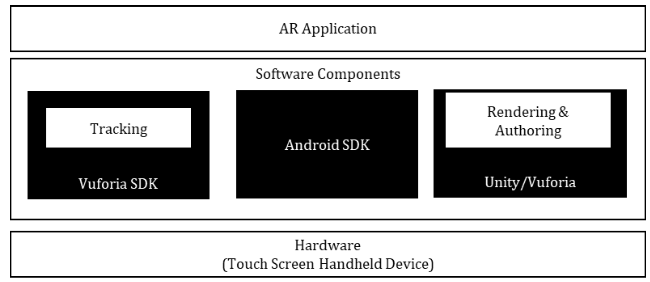


**Figure 1: Software Components of Prototypes 1 & 2**

The prototype is developed by generating a model target from the CAD model of the WMF coffee machine using a model target generator. A 3D model of the WMF coffee machine was generated based on the same CAD model. Vuforia SDK (9.3.3) has been used to implement the generated model target and 3D model for AR prototype development, using Unity 2019.3.12f1 as the IDE. When the mobile camera detects the WMF coffee machine using the generated model target as shown in Figure 2, the 3D model is displayed onto the real environment along with other functionalities such as choosing the menu (to see the AR instructions, text annotations to view the parts of the coffee machine, and an app to place a call to the support). Design guidelines of AR are followed during the AR app development and focused on tracking, registration, visualization, rendering, authoring, and interaction techniques as shown in Figure 2.

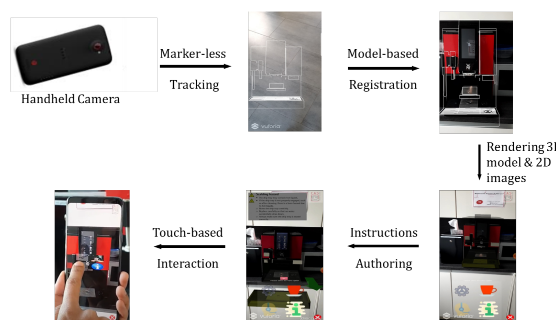


**Figure 2: Sequence of development and usage of Prototype 1 for an AR maintenance app for a coffee machine.**

**Prototype 2:** This AR system is developed for guiding robotic arm maintenance, with the target user as the Operator 4.0. A 3D model of a Robotic arm is chosen to develop an image target, and a marker-based AR system is developed to provide maintenance instructions for the Operator 4.0.

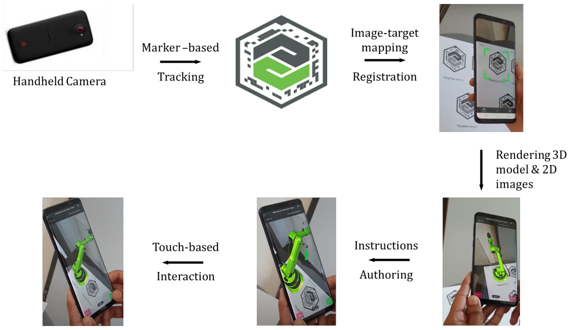


**Figure 3: Development of a 3D model-based robotic arm's maintenance**

The sequence for Prototype 2 as depicted in Figure 3 is implemented by creating the project using Vuforia studio free Trial version and by choosing the one of the provided ThingMark[1]. The 3D sequence of maintenance steps is developed using PTC Creo (student version). The scripts for placing a 3D model into a project and binding corresponding model sequences to the UI are developed using JavaScript. Then the build is deployed onto the Experience server[2] of PTC to access it using the Vuforia View app.

## 4 Evaluation and Results

14 people were invited from CAS to take part in the experimental study. The age group of the participants is from 18 to 40 years, with 8 male and 6 female participants. The questionnaire is taken in German since most of the participants were native German speakers. After basic instructions, participants interacted with both prototypes, with 5-6 minutes for the first prototype, and 10 minutes for the second. Following this, participant experience with the prototypes was evaluated by means of a follow-up questionnaire, which took typically up to 5 minutes. The Questionnaire consists of three categories: usefulness of the AR features, efficiency of prototypes in maintenance and 3D visualization quality. Participants rated the questions mentioned in the questionnaire on a scale of 1 to 6 (1 being extremely disagree and 6 being extremely agree).

Concerning usability and operability of the developed prototypes (RQ2), the participants found great potential in both AR prototypes, and found them to be intuitive and useful in the area of maintaining industrial equipment robotic arm and household equipment coffee machine. As a user with little AR experience, it was easy to use both applications. The ability to navigate in the different steps of the maintenance activities using Previous/next buttons to go back and forth was rated highly. Suggestions were provided by the participants to improve the interface aspects, such the font size of the texts and visibility of UI elements. Another important suggestion was to display context-sensitive information if the element is not visible in a minimum size and to highlight the element by marking it with an arrow or circle to indicate in which part of the equipment the Operator had to focus to follow the maintenance instructions. The majority of the participants showed less interest in the audio command on instructions guidance. Response by the selected participants was clear to analyze the usefulness of AR prototypes in the maintenance of equipment.

Regarding maintenance goals (RQ3), 12 of 14 respondents agreed that AR can be applied in machine maintenance as a training and maintenance guide, whereas 11 participants agreed that AR maintenance applications reduce service time in maintenance and operating machines. All participants believed that AR systems significantly help in reducing errors during the maintenance activity and 13 participants believed that AR systems can replace manual documents for maintenance.

## 5 Conclusion

In this work, two AR prototypes were developed for maintenance purposes, while regarding state-of-the-art AR technologies and design guidelines for the Operator 4.0. While AR has a high potential to be used as a visual aide for maintenance activities, barriers do exist to the proliferation of AR apps, in terms of modeling and design expertise needed to create AR-based maintenance apps. The work also indicates the benefit of AR for tutorial and teaching purposes, particularly for complex machinery. In the current work, the evaluation of the prototype was carried out as a pilot study with a small group of users, and will have to be evaluated with a larger user base. The prototypes in this work have been used the platform Vuforia, which has limitations with respect to the number of trainable CAD models. Further work will have to consider open source AR Technologies such as ARCore and Wikitude, to be both extensible as well as to follow the requirements of digitally fair software[3], to ensure higher digital sovereignty and acceptance in the German engineering industry. With respect to image recognition technologies, future work needs to consider larger databases such as OpenCV, rather than relying solely on publicly available or self-designed CAD models to recognize objects and generate suitable augmentation content. Further, this work did not consider limiting conditions of industrial and production environments. Future use cases will thus have to be evaluated in larger groups, especially in industrial settings (such as with background noise, absence of good lighting conditions, availability of internet bandwidth and network connectivity issues), to assess the extensibility and robustness of AR as a technology for maintenance processes.

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